EFFECTIVE THERMAL CONDUCTIVITY OF EPOXY MATRIX COMPOSITES FILLED WITH GRANITE DUST

A Project Report Submitted in Partial Fulfilment of the Requirements for the

Degree of

B. Tech.

(Mechanical Engineering)

By

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NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

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C E R T I F I C A T E

This is certify that the work in this thesis entitled "**Thermal conductivity of epoxy matrix composites filled with granite powder**" by **Anunay Kumar Singh**, has been carried out under my supervision in partial fulfilment of the requirement for the degree of **Bachelor of Technology** in *Mechanical Engineering* during session 2013-2014 in the department of mechanical engineering, National institute of technology, Rourkela.

To the best of my knowledge this work has not been submitted by any other University/Institute for the award of any degree.

Dr. Alok satapathy

Date-06/05/2014

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C O N T E N T S

ABSTRACT

Particulate filled polymeric composites with upgraded thermo-physical properties are very popular in electronic industry. This project exhibits a numerical, analytical and experimental examination on the thermal conductivity upgrade of granite dust filled polymer composites. Watched heat flow meter test technique is utilized to measure the thermal conductivity of granite powder filled epoxy composites utilizing an instrument Unithermtm Model 2022 as per ASTM-E1530. In the numerical study, the finite element method (ANSYS) is utilized to compute the conductivity of the composites. Three-dimensional solid shape-in-3d square and sphere- in-block cross section cluster models will be utilized to recreate the microstructure of composite materials for different filler size and concentration. The effect indicates that the effective thermal conductivity increments with augmentation in volume fraction of filler material i.e. granite dust. The experimental value and numerical values of effective thermal conductivity are compared with models values. It is discovered that the values got for different composite models utilizing Finite Element Method (FEM) are in sensible concurrence with the experimental values.

Keywords: *Thermal conductivity, Polymer composite, Epoxy resin, Granite dust.*

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Chapter 1

Introduction

INTRODUCTION

Composite Materials:

Basically composite material is combination of two micro-constituents that differ both in physical and chemical combination called as matrix phase. Main function of matrix is to transfer stress between the micro-constituents fibre which helps to increase mechanical properties of composite such as strength, stiffness etc. Composites are the most common technique used by the industries to reduce the waste and to get new material of good thermal, mechanical properties and most importantly corrosive resistance. For example, the requirement of electronic industry for using light weight material with high heat conductivity if fulfilled by expensive metallic material or composite material. These materials have successfully substituted conventional material in terms of light weight, high strength and corrosive resistance etc. We can easily tell the different material of composite as they do not dissolve or blend into each other. Mainly the reinforcing materials are strong with low densities and matrix is usually ductile or tough material. Composites are designed and fabricated properly to give strength of reinforcing material and toughness of matrix to achieve a combination of desirable property. The strength of the composite which are made depends upon the type of reinforcing material and fibre in the matrix [1].

Types of composites materials:

Composites materials are dissevered into three types on the basis of matrix material. They are:

(1) Polymer composites
(2) Metal composites
(3) Ceramic composites

(1) Polymer composites:

Polymer composites (PCs) are comprised of variety of short or continuous fibre bounded together by an organic polymer matrix. PCs are of two types, thermosets and thermoplastics. Thermosets are solidified by irreversible chemical reaction, in which the molecules of the polymer cross-link of form connected chain. Example of this type of polymer composites is epoxies etc. On other hand thermoplastic are melted and then solidified, a process that can be repeated for numerous times for reprocessing.

These types of composites have low strength and low stiffness as compared to metal and ceramic composites. Polymer composites are most common in use among all other composites.

(2) Metal composites

Metal composites consist of two materials in which one of them is metal. Metal composites have many advantages over monolithic metal such as high specific strength; coefficient of thermal expansion is low. Due to its good thermal properties it has wide area of application in making of cables, housing, combustion chamber nozzle etc.

(3) **Ceramic composites**

It is composition of ceramic fibre mixed with ceramic fibre. Ceramic composites have good mechanical properties like high crack resistance, high strength, hardness etc.

Classification of polymer composites:

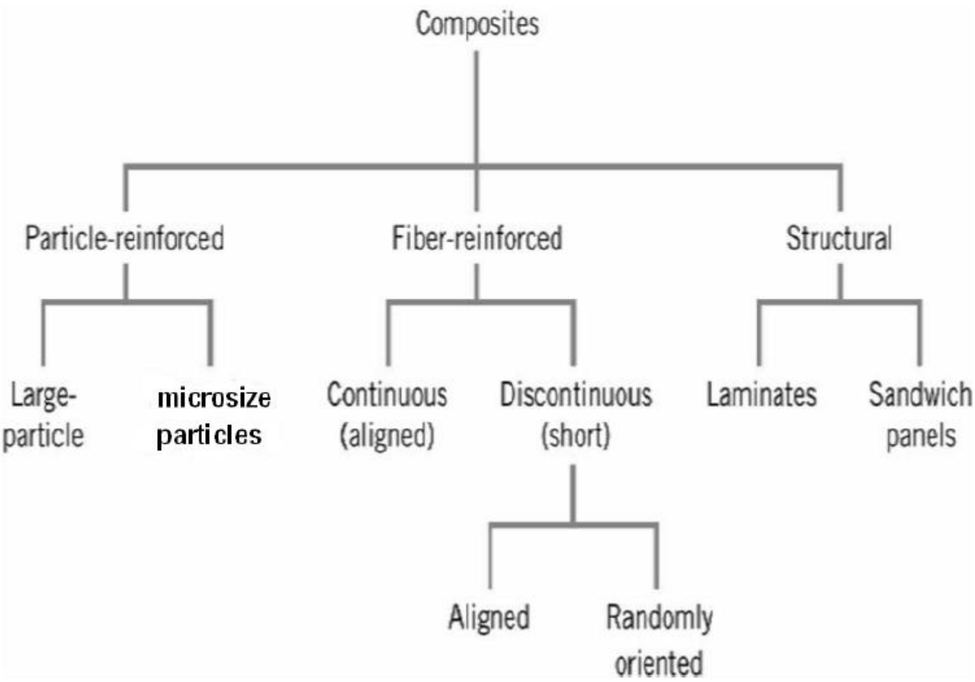

Fig. 1 Classification of composites based on reinforcement type

Polymer matrix composites can be divided into three types on the basis of type of reinforcement:

i. Particle reinforced polymer (PRP)
ii. Fibre reinforced polymer (FRP)
iii. Structural reinforced polymer (SRP)

(1)Particle reinforced polymer:

Particles are used for reinforcing which includes mineral particle, metal particle, carbon black etc. The particle diameter is of typically on the order of one micron. Reinforced Particles are used to increase modulus and to decrease the ductility of matrix. Particle reinforced composites are much easier and chip to make as compared to other reinforced polymers. The particles are simply added to the polymer melt in an extruder. Example of particle reinforced composite is auto-mobile tyre which has carbon black particles in a matrix.

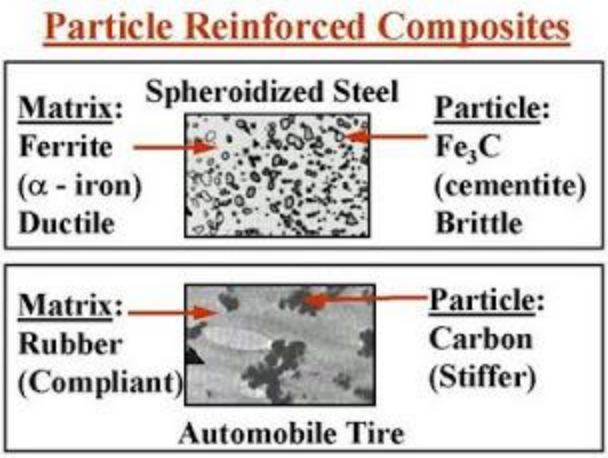

Fig.2 Particle reinforced polymer composites

(2)Fibre reinforced polymer:

A fibre reinforced polymer consists of three components: (a) the fibre as the discontinuous, (b) the matrix as the continuous phase, (c) the fine interface region. The properties of the fibre and matrix material can be combined in fibre reinforced composites to get a product which is superior in many respects to the parent material. Main source of strength in fibre reinforced polymer are fibre and matrix glues all the fibre together in shape and transfer stress between them.

These materials are light and exhibit an enhanced resistance to cracking. Resin and polyester are widely used agents.

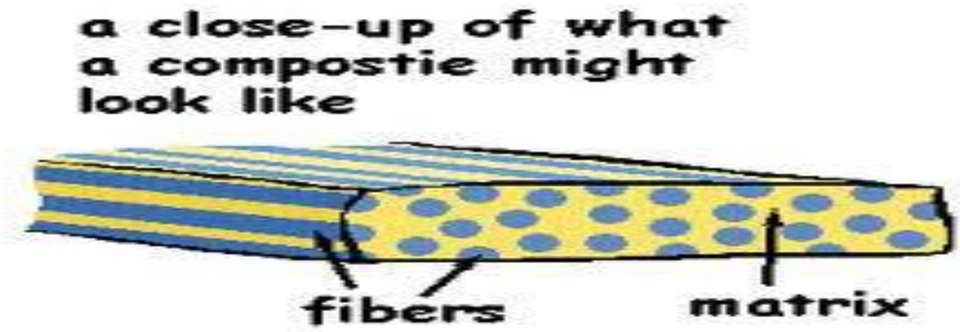

Fig. 3 Fibre reinforced polymer

(3)**Structure reinforced polymer:**

Structure reinforced polymer composites are made of number of layers held together by number of matrix. Over the last few decade polymer material have replaced many conventional materials because of its less cost and more strength.

Numerous amount of work has been done on mechanical properties of polymer composites, but few researchers have studied thermal properties of particulate filled polymers. In view of this present work has been done on thermal conductivity of epoxy filled granite dust polymer composites.

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Chapter 2

Literature Review

LITERATURE REVIEW

The purpose of the literature review is to provide background information which being carried out in this thesis. This treatise embraces on the thermal characteristics of particulate filled polymer composites which include brief review of:

(a)On Particulate filled polymer composites

(b)On different thermal conductivity models

(a)On particulate filled polymer composites:

Particulate fillers such as metal particles or ceramic are used to improve mechanical properties of material such as wear resistance [2]. These polymer composites have wide range of industrial use for example making of chips, electrodes because of their thermal resistance at high temperature [3]. These designing materials are respected because of its high corrosion resistance, low density and low cost [4-5]. Particle size vary from composites to composites, generally particle size ranges 10 micron. The consideration of inorganic fillers into polymers for business requisitions is basically pointed at the expense decrease and stiffness improvement [6, 7]. The size, shape, specific area and volume fraction of filler particles greatly effects mechanical and thermal properties [8]. Professor Yamamoto et al [9] describes about the shape and size of particles has significant effect on mechanical properties such as fatigue resistance, tensile and fracture properties.

(b)On different Thermal conductivity models:

To anticipate the effective thermal conductivity of composite materials, a few hypothetical and exact models have been proposed previously. The two fundamental comparisons of thermal conduction utilized within composites are Rule of mixture and Maxwell model [10] show that expect irregular scattering of small spheres inside a proceeds lattice to ascertain the effective thermal conductivity hold useful for low filler concentrations. Bruggeman [11] determined a mathematical statement of thermal conductivity regarding the robust stacking for spherical fillers in a dilute suspension. Lewis and Nielsen [12] adjusted the impact of the state of the particles and the introduction or sort of pressing for a two phase system. A number of them anticipate the thermal conductivity by knowing the filler concentration. For a two-part composite, the easiest choices might be with the materials orchestrated in either series or parallel with respect to heat flow.

For parallel conduction model:

$$k_{eff} = (1-\phi_f)k_p + \phi_f k_f \qquad (1)$$

For series conduction model

$$1/k_{eff} = (1-\phi_f)/k_p + \phi_f / k_f \qquad (2)$$

The relationships displayed by Equations. (1) and (2) are determined on the premise of the Rules-of-mixture. Maxwell got an exact solution for the conductivity of arbitrarily conveyed and non-interacting homogeneous spheres in a homogeneous medium.

$$\frac{k_{eff}}{k_p} = \left(\frac{k_f + 2k_p + 2\phi_f (k_f - k_p)}{k_f + 2k_p - \phi (k_f - k_p)} \right) \qquad (3)$$

Thermal conductivities for low filler concentrations are anticipated exceptionally well utilizing this model; however when there is an increment in filler concentrations, conductive ties is begun to structure on the grounds that the molecule begins to interact with one another, this leading chain is toward direction of heat flow, that is the motivation behind why the quality of effective thermal conductivity are belittled for the above model. All the models talked about above computed effective thermal conductivity on the premise of volume fraction of the filler however none of the model has dealt with the arrangement of the filler into the matrix. On that premise, writers proposed a hypothetical model acknowledging distribution of particles into the matrix too alongside the volume fraction of filler in their prior work [2]. The interpretation for computing effective thermal conductivity proposed by authors is given by

$$k_{eff} = \frac{1}{\dfrac{1}{k_p} - \dfrac{1}{k_p}\left(\dfrac{6\phi_f}{\pi}\right)^{\frac{1}{3}} + \dfrac{4}{\left(k_p\left(\dfrac{4\pi}{3\phi_f}\right)^{\frac{2}{3}} + \left(\dfrac{2\phi_f}{9\pi}\right)^{\frac{1}{3}} 2\pi\left(k_f - k_p\right)\right)}} \quad (4)$$

Where Φ speaks to the volume fraction and k is the thermal conductivity, postfix f and p are for filler and matrix material.

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Chapter 3

Materials and methods

MATERIALS AND METHODS

This section manages materials and techniques utilized for making of composites under this project. This part additionally tells about the characterization and thermal conductivity test which the specimens are subjected to. For determination of thermal conductivity focused around Experimental strategies, Analytical method and Finite component method are also portrayed in this part.

MATERIALS

Matrix Material:

Epoxy LY 556, its basic name is Bisphenol-A-Diglycidyl-Eather and synthetically fits in with "epoxide" family is utilized as matrix material. Epoxy resins go under the class of thermoset alongside silicones and polyester. Epoxy LY 556 resin and comparing hardener (HY 951) supplied by Ciba Geigy India Limited, is blended in a degree of 10:1 by weight as proposed. Epoxy is basically picked on the grounds that it happens to be most usually utilized polymer having low density (1.1gm/cc) and low esteem of thermal conductivity (about 0.363 W/M-K). Around the vast extent of polymers accessible in business cured epoxy resin is generally utilized for the electronic business as a part of circuit board requisition.

Filler Material:

Granite an industrial waste is an igneous hard rock consists of 20% quartz by volume. It has high strength, stiffness and better wear resistance properties. Granite powders are largely available in stone crushers and in granite stone mines [13]. Density of granite is 2.7 gm/cc and its thermal conductivity is 2.85 W/m-K.

Fig - Granite dust

Properties of granite dust

Chemical properties:

(1) Chemical composition

Silica (70-77%), alumina (11-13%), soda (3-5%), lime (1%)

(2) General composition

(a) Quartz (10-60%)

(b) Feldspars (65-90%)

Physical properties:

Physical properties of granite dust are:

(1) Density – 2.7 gm/cc
(2) Thermal conductivity – 2.85 w/m-k
(3) Melting point – 3000 F
(4) Solubility in water – insoluble
(5) Appearance – Black and white spackled rock
(6) Odourless

Composites Fabrication:

Epoxy LY 556 resin and corresponding hardener (HY 951) are mixed in ratio of 10:1 by weight as recommended. Granite powder with an average particle size of 90-100 µm are reinforced with epoxy resin (density 1.1 gm/cc) to prepare the composites. Epoxy mixed with granite powder is slowly decanted into the paper cup spread with thin layer of silicon releasing agent. The composites are prepared by conventional hand lay-up technique in paper cup so as to get the specimen of cylindrical shape of diameter around 50mm and thickness of 10mm. Composites of six different compositions with 0vol%, 5vol%, 10vol%, 15vol%, 20vol% and 25vol% are prepared accordingly. The castings are left at room temperature of around 24 hours after which the paper cups are broken and sample is released.

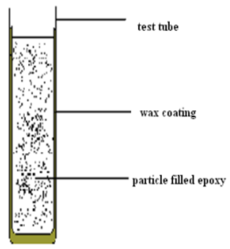

Fig. 3.1 Preparation of particulate filled composites by hand-lay-up technique

THERMAL CONDUCTIVITY CHARACTERIZATION

Experimental Determination of Thermal Conductivity:

Unitherm™ Model 2022 is used to measure the effective thermal conductivity of polymer composites which works on the principle of double guarded heat flow method. Low to medium thermal conductivity materials such as glasses, rubbers, polymers can be measured.

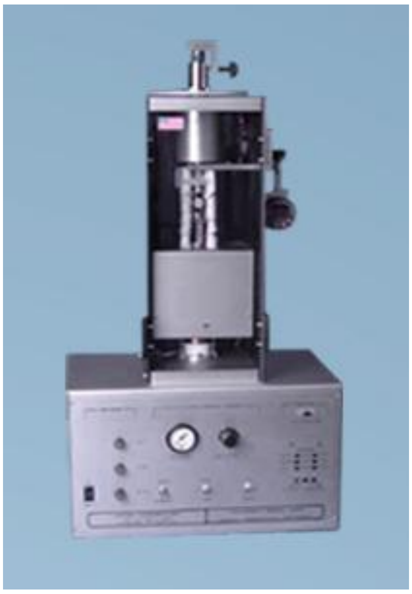

Fig. 3.2- Unitherm™ Model 2022

Numerical analysis by Concept of Finite Element Technique :

The premise of Finite Element Technique is to separation the area into limited number of sub-space for which the efficient inexact result is built by applying the variety or weighted residual methods. The FEM is a numerical process that might be utilized to take care of substantial engineering issues, for example, heat transfer, stress investigation, fluid flow. ANSYS is finite element modelling bundle for numerically settling an extensive variety of mechanical issues that incorporates heat transfer, fluid flow, and structure analysis and so on.

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Chapter 4

Results and Discussion

RESULTS AND DISCUSSION

Table 4.1 shows the variation in the value of k_{eff} when micro-sized granite dust particles is added in epoxy matrix. It shows the comparison between the values obtained from various established theoretical model, experimental values and the model proposed by the authors in their earlier work. It is clear from the table that there is significant increase in value of k_{eff} as the concentration of granite dust particles is increases.

Table 4.1-.Effective thermal conductivity of polymer composites obtained from different models and experimental values

Sl.	Filler content,Vol%	Rule of Mixture	Maxwell's model	Proposed model	Experimental values
1	0	0.363	0.363	0.363	0.363
2	5	0.379	0.402	0.519	0.424
3	10	0.398	0.444	0.584	0.513
4	15	0.417	0.490	0.653	0.584
5	20	0.439	0.538	0.731	0.799
6	25	0.464	0.592	0.818	1.20

Also it is clear that while none of the established model is predicting the k_{eff} values correctly, only the proposed model are in close approximation with the measured values. An interesting fact is noticed from the table that measured values are in close approximation with the proposed model only up to 20vol % after which a sudden jump in the value of measured k_{eff} is observed. This is because of the creation of conductive chain when the filler content in the matrix is expanded past certain quality. The vol % at which such sudden rise in the value of k_{eff} is observed is called percolation threshold. It is likewise intriguing to note that with expansion of 25 vol % of granite dust particles, k_{eff} of epoxy expansions to 231 %. So it can be seen that granite dust, an industrial waste can successfully replace the costly metals and ceramics particulate when thermal conductivity is in consideration.

THERMAL CONDUCTIVITY CHARACTERIZATION

Description of the problem

For requisition of composite material and functional design, determination of viable properties of composite materials is principal vitality. The most essential component that impacts the effective property and could be controlled to a certain degree is the micro structure of the composite. Micro structure alludes to shape, size and dispersion of particles in the reinforcing matrix.

Using ANSYS, thermal analysis is carried out for the conductive heat transfer through the composite body. To estimate thermal analysis of three dimensional models with spheres has been used to simulate the polymer composite with different filler concentration. Effective thermal conductivity of epoxy filled with granite dust polymer composites up to 25% of volume is numerically determined by ANSYS software.

Assumptions:

For analysis of ideal case following assumptions are taken into count:

(1) Thermal contact resistance between lattice and filler is irrelevant.
(2) Both matrix and filler are homogeneous in nature.
(3) The polymer composite is free of voids.
(4) Polymer composites which are prepared are perceptibly homogeneous.

Numerical analysis:

Temperature of the surface ABCD is taken as T_1=100^{0}c and the heat transfer coefficient is considered as 25 w/m^2 k at barometrical temperature of 25^{0}c. The limit conditions and the heat flow direction for model as demonstrated beneath in figure 4.1. Alternate surfaces of solid shape, parallel to direction of heat flow is taken as adiabatic. Temperatures at inner part locale of 3d square are known by ANSYS.

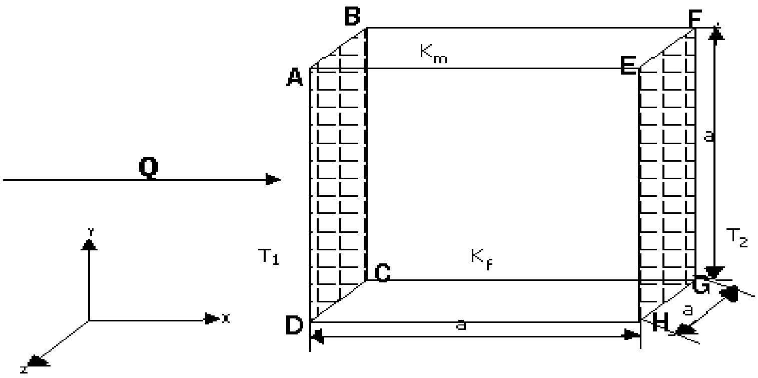

Fig 4.1- Boundary conditions

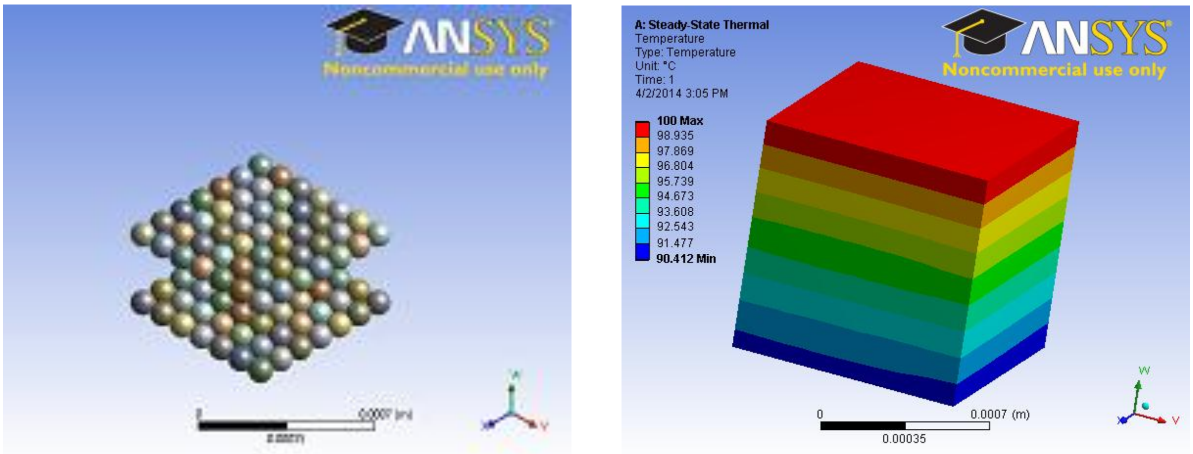

Fig 4.2- Temperature profile for composite with particle concentration of 5.3 vol%

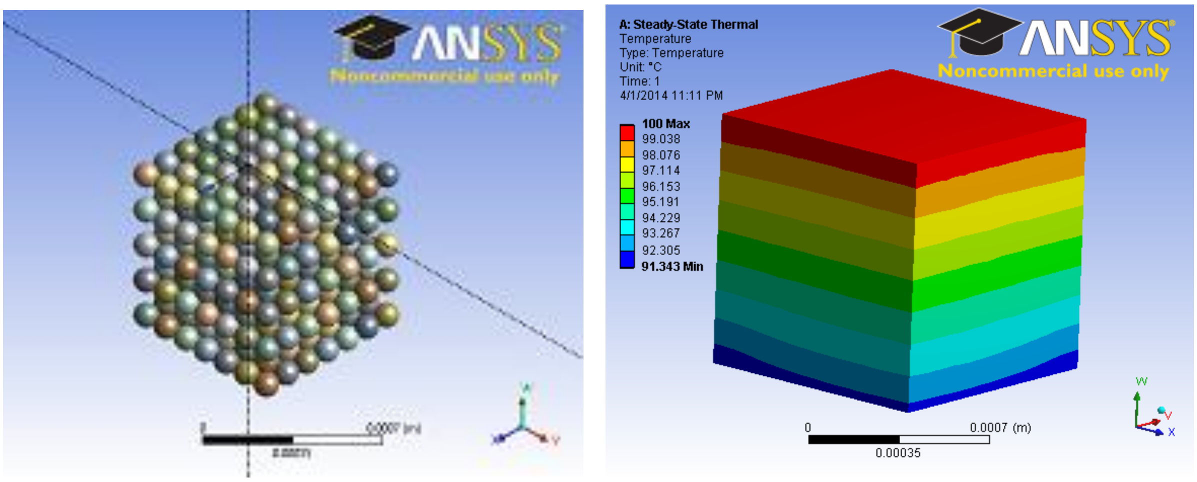

Fig 4.3- Temperature profile for composite with particle concentration of 12.8 vol%

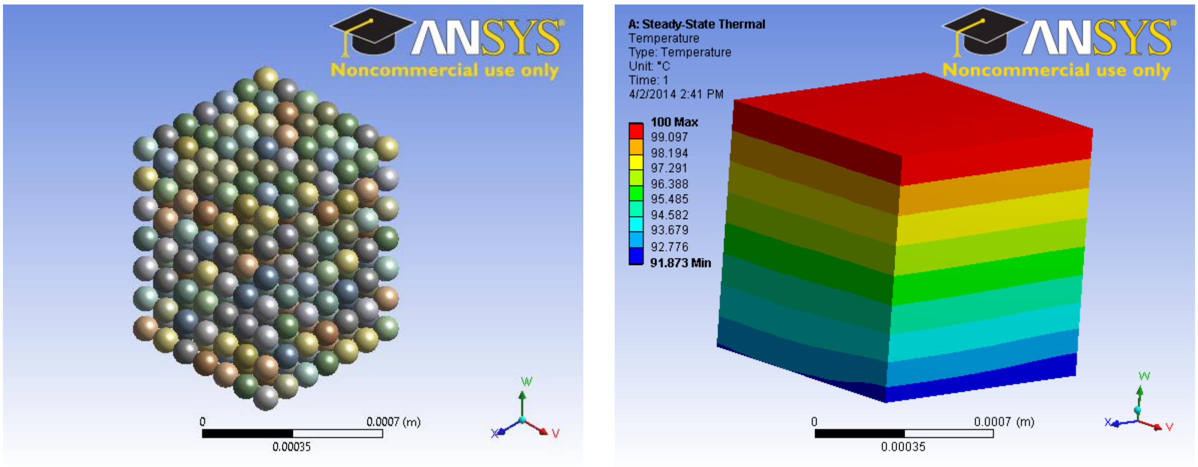

Fig 4.4- Temperature profile for composite with particle concentration of 17.96 vol%

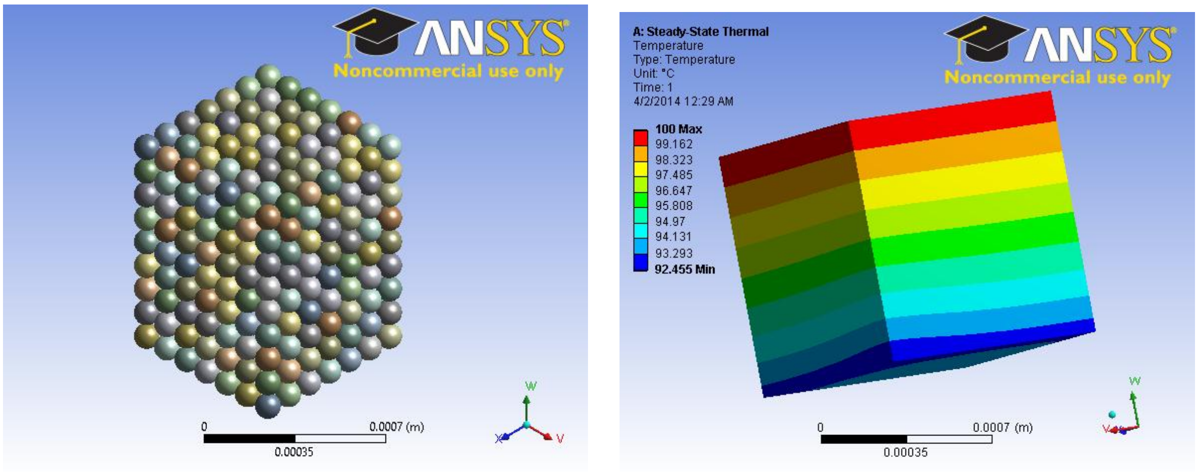

Fig 4.5-Temperature profile for composite with particle concentration of 23.1vol%

Serial no.	Volume Fraction(ϕ)	K_{eff} (Exp)	K_{eff} (FEM)	K_{eff} (Model)	K_{eff} (ROM)	K_{eff} (Maxwell)
1	0	0.360	0.360	0.363	0.363	0.363
2	5	0.424	0.355	0.519	0.379	0.402
3	10	0.513	0.367	0.584	0.398	0.444
4	15	0.584	0.3798	0.653	0.417	0.490
5	20	0.799	0.3912	0.731	0.439	0.538
6	25	1.2	0.5728	0.818	0.464	0.592

Table 4.2-Thermal conductivity for composites obtained from models, experiment, FEM

Serial no.	Vol%	FEM(%)	Model(%)	ROM(%)	Maxwell(%)
1	5	-18.86	22.4	-10.61	-5.19
2	10	-28.46	13.84	-22.4	-13.45
3	15	-34.96	11.82	-28.6	-16.09
4	20	-51.04	8.51	-45	-32.67
5	25	-52.26	-31.83	-63.33	-50.67

GRAPH:

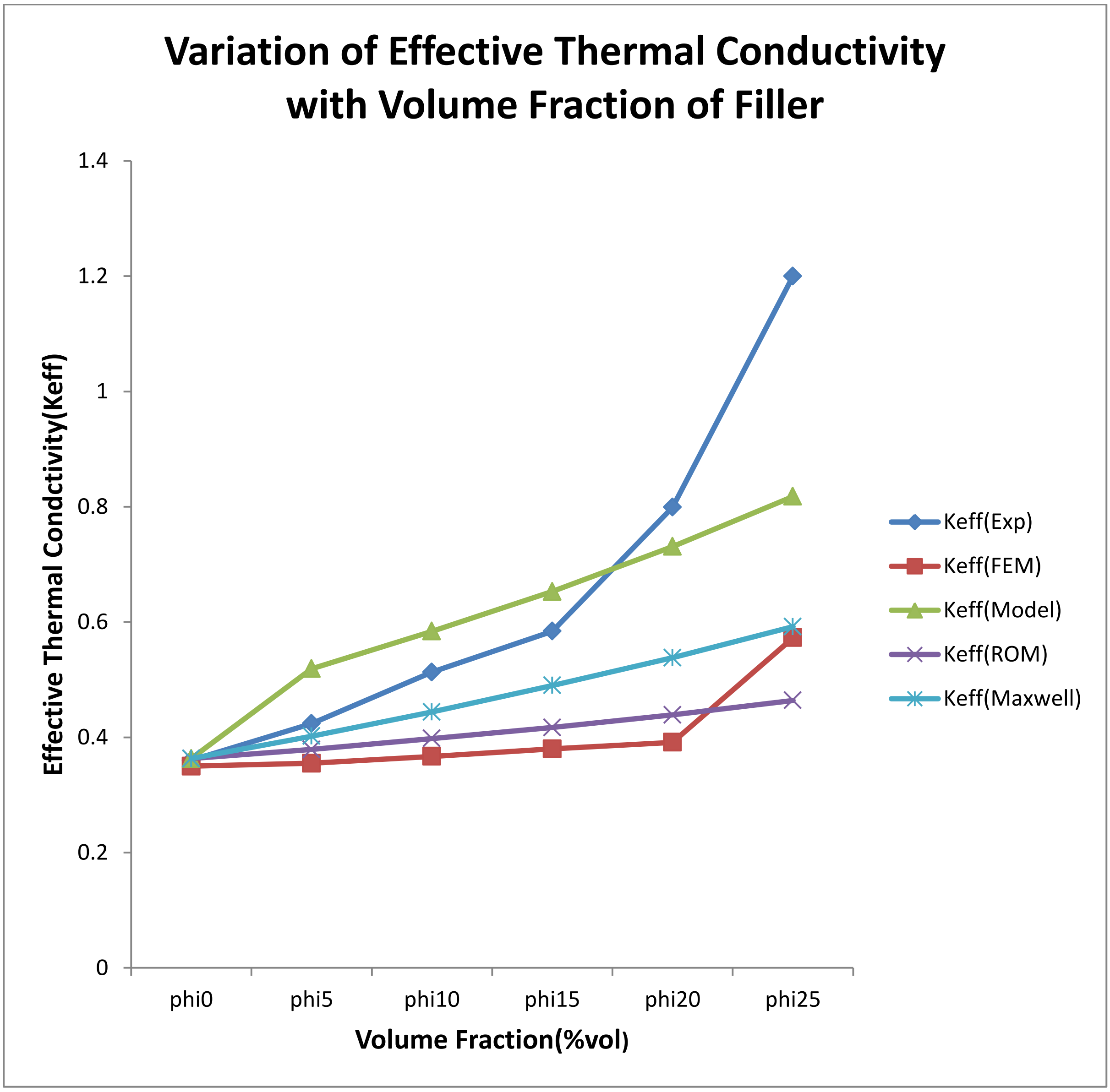

Fig 4.6 Comparison between various models value, experimental value and FEM values in line graph

Histogram Graph:

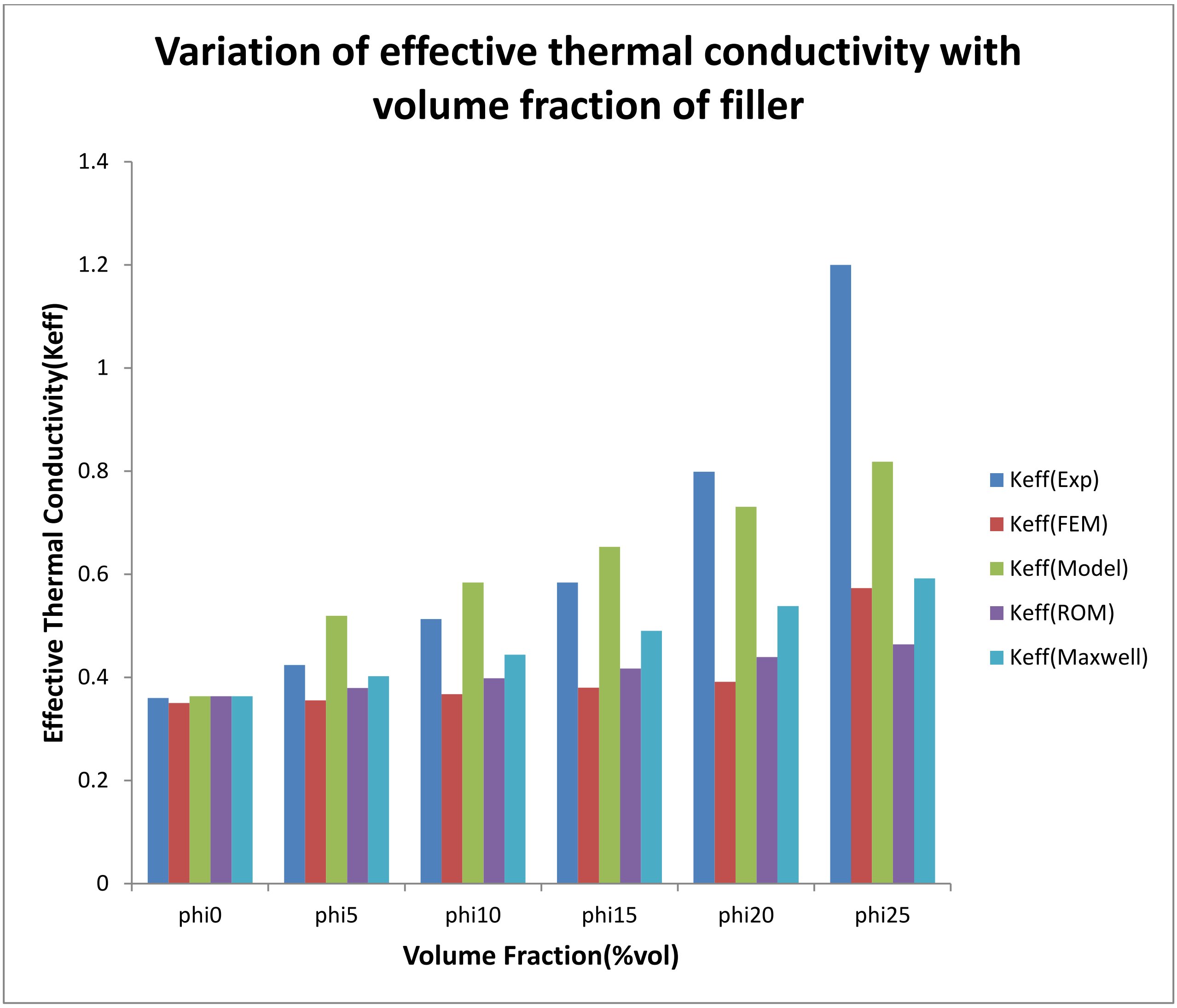

Fig 4.7 Comparison between various models value, experimental value and FEM values in histogram graph.

Thermal conductivity of epoxy composite filled with granite dust particles up to 25 vol% are numerically calculated by FEM and numerical result is compared with existing models value and experimental values.

The above study tells that FEM can be employed to determine the effective thermal conductivity for these composite with varying amount of filler concentration. Incorporation of granite powder results in increment of thermal conductivity of epoxy resin. An improvement of about 231% in the value of k_{eff} is recorded with addition of 25% of granite dust in epoxy resin.

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Chapter 5

Conclusion

CONCLUSIONS AND SCOPE FOR FUTURE WORK

In view of the analytical, Exploratory and numerical work reported above, it could be inferred that:

- Sets of epoxy/granite dust composite might be effectively manufactured by essentially hand lay-up procedure.
- From exploratory value, it could be watched that expansion of granite dust by 25% by volume enhances the thermal conductivity around 231%.
- FEM can be used to measure the effective thermal conductivity of the composites with varying granite dust concentration.
- The above fabricated composites can be found its potential application in electronic field, printed circuit boards, heat sink etc.

Scope for future work:

Above research work leaves a wide extension for future to investigate others part of thermal behaviour of granite powder filled epoxy composites like change in thermal behaviour by fluctuating filler shape and size and research on new fillers for improvement of thermal conductivity of composites.

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Chapter 6

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